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The fabrication of a customized occlusal splint based on the merging of dynamic jaw tracking records, cone beam computed tomography, and CAD-CAM digital impression

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Abstract:

OBJECTIVES: The aim of this case report was to present the procedure of fabricating a customized occlusal splint, through a revolutionary software that combines cone beam computed tomography (CBCT) with jaw motion tracking (JMT) data and superimposes a digital impression.

MATERIALS AND METHODS: The case report was conducted on a 46-year-old female patient diagnosed with the temporomandibular disorder. A CBCT scan and an optical impression were obtained. The range of the patient's mandibular movements was captured with a JMT device. The data were combined in the SICAT software (SICAT, Sirona, Bonn, Germany).

RESULTS: The software enabled the visualization of patient-specific mandibular movements and provided a real dynamic anatomical evaluation of the condylar position in the glenoid fossa. After the assessment of the range of movements during opening, protrusion, and lateral movements all the data were sent to SICAT and a customized occlusal splint was manufactured.

CONCLUSIONS: The SICAT software provides a three-dimensional real-dynamic simulation of mandibular movements relative to the patient-specific anatomy of the jaw; thus, it opens new possibilities and potentials for the management of temporomandibular disorders.

Keywords:

Cone beam computed tomography, digital impression, jaw motion tracking, occlusal splint, temporomandibular disorders

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Introduction

Occlusion and its relationship to the function of the masticatory system is complex and remains a topic of great interest. The dento-periodontal complex, the temporomandibular joints (TMJs), and the masticatory muscles are interrelated components of the stomatognathic system[1] and are regulated by an intricate neurologic control system. Temporomandibular disorders (TMDs) include a number of conditions characterized by signs and symptoms involving the TMJ, masticatory muscles, or both.[2] Approximately, 33% of the population has at least one TMD symptom and 3.6–7% of the population has TMD with sufficient severity to cause them to seek treatment.[3,4]

Many dental specialties have been involved in the diagnosis and treatment of TMDs, but most of their means have been based on empirical data and biased clinical experience.[5] Two decades ago, a significant ruling in the US court resulted in a judgment

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against a Michigan orthodontist for causing TMD in a 16-year-old girl, prompted the orthodontic community to re-evaluate the relationship between orthodontic treatment and TMD.[5] Since then, many studies have been conducted in order to elucidate the relationship between orthodontics and TMD, but significant controversy still persists. The main issues that are raised are whether orthodontic treatment is capable of improving the symptoms of TMD and whether it predisposes to the development of TMD. A systematic review conducted in 2010 concluded that there is no evidence to show that orthodontic treatment can prevent or relieve TMDs.[6] However, the call for contemporary orthodontics to deal with the management of TMDs is evident, since the prevalence of mild TMD signs has been reported to be high in the general population.

The study of mandibular motion is essential to the management of TMDs. The need to duplicate the mandibular movements extra-orally led to the employment of various methods to record and analyze them.[7-13] Patient information can be transferred to an articulator with mounted casts and thus, mandibular movements can be evaluated. Using central relation as a reference point, interarch movements of the articulator are possible.[13] However, there are several limitations concerning bite registration and articulators. Bite registrations are static recordings; thus, articulators are unable to record real life dynamics of occlusion during mandibular movements. Another basic limitation is the lack of visualization of condyle position, which is essential to the management of TMDs. There are also various difficulties with transferring the registration onto the articulator and mounting the casts with accuracy.[14] Cone beam computed tomography (CBCT) in conjunction with jaw tracking devices enabled the virtual evaluation of the occlusion and the TMJs and helped substantially in overcoming these problems. In the early years, several methods using mechanical devices including marking needles had been proposed, but all of them had the disadvantage of causing interferences with natural jaw movements. Later, an apparatus based on the principles of pantograph was introduced. It consisted of a recording styli and recording plates, but the transferred recordings were inaccurate. The case gnathic replicator was presented, but its main downside was that jaw movements could be influenced by the weight of the apparatus. Many photographic methods were also used, including cinematographic methods and photo-anthropometry, but most of them proved to be unsatisfactory. Roentgenographic methods have also been used in the past, but their use is doubtful due to radiation exposure.[15] Mechano-electronic recorders and optoelectronic recorders that register mandibular movement electronically have been developed in order to improve precision and efficiency.[13] In mechano-electronic recorders, mandibular movement is recorded by the digital contact plates and processed by the software. Optoelectronic systems have sensors that are optically tracked by cameras. Both of them are light weight and require relatively little time, but their cost is high.[13]

Several techniques can be used to image the TMJ including panoramic radiography, plain radiography, conventional CT, and CBCT. The hard and soft tissue structures of TMJ have been reconstructed by spiral and helical CT and magnetic resonance imaging (MRI).[16] There are previous studies that have merged these data with jaw movement recordings by ultrafast MRI, electromagnetic tracking device, or optoelectric measuring systems.[16,17] MRIs disadvantages are related to the high cost and the need for the patient to lie down during MRI imaging, which might alter normal jaw movements. It is also contraindicated to patients with pacemakers and metallic heart valves.[16,18] The disadvantage of the conventional CT is that it shows higher exposure values than CBCT.[19] CBCTs main advantage is the observation of boney joint structures in all three planes in addition to the possible image manipulation at different depths and three-dimensional (3D) reconstruction.[18]

The digital intraoral impression was introduced for single unit restorations but in recent years, the accuracy of these systems has improved to capture larger areas up to full-arch impressions. The main advantages of digital impression are the time saved, the reproducibility of the method, and the fact that without placing material inside the patient's mouth the possibility of eccentric movements is reduced.[20]

The purpose of this case report as to present a new technique to capture the range of motion of jaw tracking and the translation of the information into a fully CAD-CAM fabricated occlusal splint.

Materials and Methods

Subject description

A 46-year-old female patient presented with a chief complaint of feeling like her teeth are moving and her bite is changing. She also complained about her front teeth chipping. She had a symmetric maxillofacial structure in the frontal view and a shorter lower facial height. Extra-orally her profile was slightly convex with a retrusive lower lip. Intra-orally her molar relationship was Class I on both sides and her overbite was 9 mm. Her upper dental midline was coincident with face midline and the lower dental midline deviated 1 mm to the left. Cephalometric analysis indicated a skeletal II Class relationship, mild retrognathic mandible, and protrusive upper incisors. The patient mentioned that she has had

TMJ issues her whole life including symptoms of clicking and pain. In the past, pharmacologic therapy (muscle relaxants) had been prescribed to her. The patient has never had previous orthodontic treatment [Figure 1]. Eventually, it was decided to fabricate a noninvasive, therapeutic splint in order to reduce the symptoms. This CAD-CAM fabricated splint was achieved through a new software application, SICAT Function (SICAT, Sirona, Bonn, Germany), which directly combines and merges 3D CBCT and electronic jaw motion tracking (JMT) data. The software also imports digital impressions taken with intraoral scanners and integrate them in functional movement displays.[21] The SICAT JMT$^+$ system is an electronic recording system that is based on 3D ultrasound measurements and records the lower jaw movements of the patient in all degrees of freedom. A detailed description of the methods and dynamic clinical simulation of mandibular movement of a patient was performed and presented.

Cone beam computed tomography

The CBCT device (Sirona, Galileos, Bensheim, Germany) was used, which acquires the images with a scan time of 14s, capture the maxilla-mandibular region in a 210 rotation, and has, according to the manufacturer, a reported radiation dosage of 29 μSi to 54 μSi. The voxel size is between 0.15 mm and 0.30 mm and the grayscale is 12 bit. The field of view is a spherical volume of 15 cm. The data from the CBCT were transferred from the scanner to a workstation, where GALAXIS 3D software (Sirona, Galileos, Bensheim, Germany) constructed 3D images. The data were saved as DICOM format (digital imaging and communication in medicine).

A CBCT scan was taken for the assessment of TMJs. The FusionBite reference tray is a transfer tray which enables the precise merging of CBCT and JMT data sets. There are eight radiopaque markers on the FusionBite tray, which are used as landmarks for the fusion of CBCT and JMT data. Silicone impression material was put in the maxillary and mandibular side of the FusionBite tray, and the patient was asked to bite on the material and wear the tray during the CBCT scan.

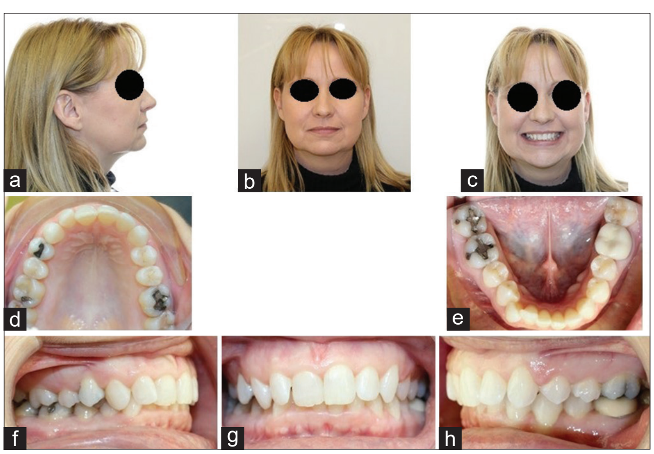

Figure 1: Facial and intraoral photographs of the patient. (a) facial profile, (b) facial front view, (c) facial front smiling, (d) upper arch, (e) lower arch, (f) intraoral right lateral view, (g) intraoral frontal view, (h) intraoral left lateral view

Jaw motion tracking

SICAT JMT$^+$ is the jaw motion tracker used to record and measure jaw position and movement. The system converts the propagation times of multiple acoustic signals into spatial information.[21] The paraocclusal attachment of the ultrasonic transmitter is to be attached to the patient and blocks occlusal bite relationships. It is adjusted to the low jaw dental arch, supplemented with autopolymerizing composite to the bending part of the T-attachment and adapted and hardened to the tooth surfaces. Excess and sharp material was removed. As a result of this procedure, functional movement of the jaw in the occlusion was undisturbed since the maxillary teeth were not in occlusion. The measurement sensor technology consists of a receiving sensor and a transmitting sensor.

The upper jaw sensor was positioned stably on the patient's head, making sure that the headband was on the patient's skull the nasion support did not stretch the skin in the nasion area. The elastic neckband was tightened comfortably for the patient. The FusionBite tray with the impression was positioned in the patient's mouth, and it was checked that the patient bit into the right position. The T-attachment was also placed in the patient's mouth. The SICAT JMT$^+$ software was started and prepared for measurement. The lower jaw sensor technology is fitted with a special locking mechanism for fixing it to the attachment. After the lower jaw sensor was attached to the SICAT FusionBite and then clicking "record," the software guided the program throughout the whole calibration sequence. The SICAT JMT$^+$ lower jaw sensor was attached to the paraocclusal T-attachment and then "record" within the software. Subsequently, the SICAT FusionBite was removed and the sensor was mounted on the attachment so that the process of functional analysis could begin. Patient jaw movement including jaw opening and closing movements to and from the habitual intercuspal position, lateral and protrusive movements, and chewing were recorded [Figure 2].

Merging cone beam computed tomography and jaw motion tracking data sets

The CBCT (DICOM format) and JMT data were loaded in the SICAT Function software. The software automatically aligned the data sets after radiopaque markers on the FusionBite tray were chosen. All jaw movements and position data that were recorded by the jaw motion tracker could be accessed directly after merging.

Hard tissue segmentation

In order to simulate the virtual jaw tracking, Sicat Function Software was used to perform mandibular and glenoid fossa segmentation. After a segment of the mandible was selected by drawing marks on the radiographic sectional slices, the software extracts CBCT data and merges it with the corresponding jaw motion data. The system then presents a 3D image of the patient-specific mandibular movement on the screen.

Superimposition of the digital models

Full-arch optical impressions of the patient were obtained with an intraoral scanner (Sirona, CEREC Omnicam). Subsequently, they were imported and merged with the CBCT data in order to obtain metrically correct images. The SICAT Function software loaded the data and superimposed the arches on the CBCT images, simultaneously with the mandibular and condylar segmentation [Figure 3]. This procedure gives the possibility to assess the dynamic occlusion and mandibular movement in interaction with TMJ function. Based on the assessment of the mandibular movements during opening and lateral movements, an occlusal splint was fabricated which intended to disengage the posterior teeth, eliminate their influence in the function of the masticatory system, and increase the patient's vertical dimension (anterior guidance). The splint was manufactured by SIRONA after all the data were sent [Figure 4].

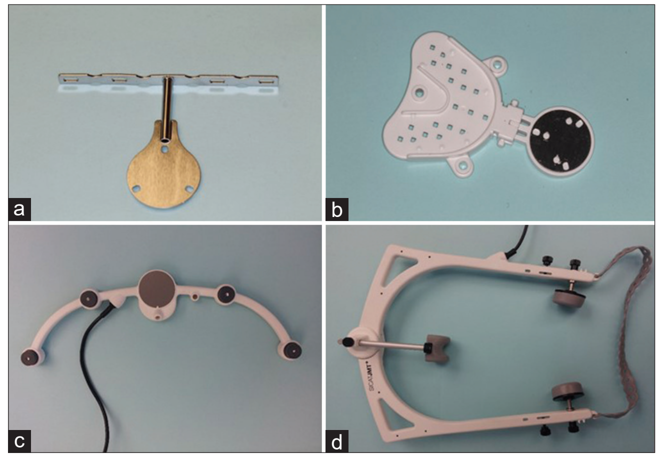

Figure 2: (a) T-attachment, (b) FusionBite Tray, (c) lower jaw sensor, (d) facebow type 13R with nasion support, neckband, and headband

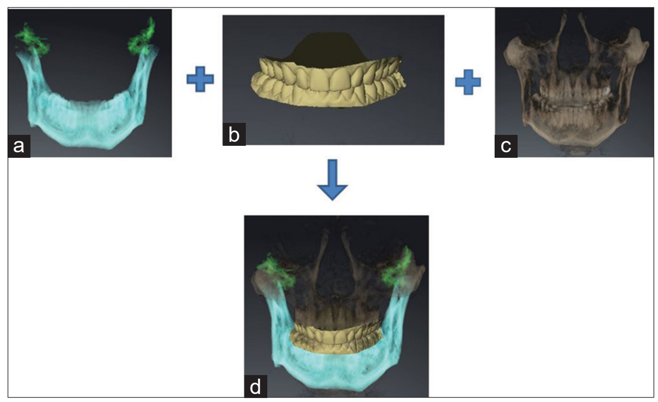

Figure 3: (a) Mandibular and condylar segmentation, (b) digital impression, (c) cone beam computed tomography, (d) merge of mandibular condylar segmentation and cone beam computed tomography with the optical impression superimposed

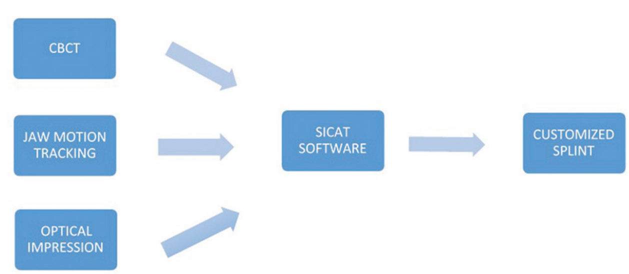

Figure 4: Fusion of cone beam computed tomography, jaw motion tracking data, and digital impression in the SICAT software, which eventually fabricates the occlusal splint

Results

Since the system can measure 3D position and rotation in all six degrees of freedom, during the procedure all mandibular movements were recorded including mouth opening and closing, right and left lateralization [Figure 5], protrusive [Figure 6], and chewing. The ranges of these movements were automatically displayed. During opening, the maximum opening was recorded and during lateral movements and chewing the range of mandibular incisors was recorded (the reference point is located at the interincisal point of the lower anterior teeth). During protrusion, the excursion of both condyles, condyle inclination in reference to Frankfurt plane and the range of lower anterior teeth were recorded. All movements could be shown in different planes.

The SICAT Function software performed mandibular segmentation after drawing marks on the radiographic sectional slices. Segmentation of the glenoid fossa was also performed. After merging the CBCT and the JMT data, the software also displayed interincisal point movement of the lower incisors during chewing. The path of any selected point of the mandible or the condyles could be displayed. After superimposing the digital models, the software presented a real, dynamic simulation of mandibular movements, in addition to the visualization of the condyle and its movements in the glenoid fossa. All the above data allowed SIRONA to fabricate a custom-made splint to fit the needs of this individual patient. The appliance covered the maxillary teeth and rugae, providing anterior guidance. The patient reported immediate relief from TMJ symptoms and kept wearing it every night after 3 months of the appliance.

Discussion

The TMJ is a complex joint and has been proved quite difficult to study and understand. An accurate evaluation of the mechanics of the TMJ is important to distinguish between healthy and diseased joints. Many devices and methods in the past have been used to measure mandibular movement, but contemporary computed technology is more accurate and has helped to improve our knowledge about temporomandibular disorders.[17] This article presented the use of SICAT Function software, which enables an anatomically precise and real dynamic rendering of jaw movement. A real patient-specific condylar position can be displayed within a 3D volume. The ranges of all mandibular movement are easily recorded and assessed and even changes in the gap between the condyle and the fossa can be measured during movements or at resting position. The advantage of this system is that it takes into account the forces of jaw movement and include them in the overall analysis.[21]

The production of 3D images brings a new level of diagnostic accuracy and detail in modern CT scanners. CBCT is a promising method to visualize hard tissue changes with a relatively low radiation dose. SICAT Function allows the fusion of three technologies that had not been used together: 3D imaging, JMT, and digital impressions. The 3D presentation of the positions and movement paths of occlusal points provides important information on the movement behavior of the mandibular joint and the teeth on the lower and upper jaw. Any dysfunction and limitations of movement can be analyzed and documented. The system records only natural mandibular movement relative to the head, so head movement and position do not affect the measurement results. The software provides a high degree of accuracy, and it is easy to use. After loading the CBCT data and JMT files in the software and superimposing the optical impression, fabrication of the splint is possible with little further work. The mandibular position to fabricate the splint was chosen ensuring disengagement of the posterior teeth and based on the lateral movements anterior guidance was provided [Figure 7]. The specific mandibular position that was chosen (which determines the thickness of the acrylic material) is associated with relaxed positioning elevator muscles allowing the articular disc to obtain an anterior and superior position over the condylar head. The system provides a complete virtual articulation of the jaws and the condyle in the glenoid fossa, in addition to a 3D simulation of the occlusion, lateral movements, and protrusion. Thus, the splint that is fabricated is accurate, adjustment time is reduced, and valuable chair time is saved. The splint also fits easily in the freeway space [Figure 8].

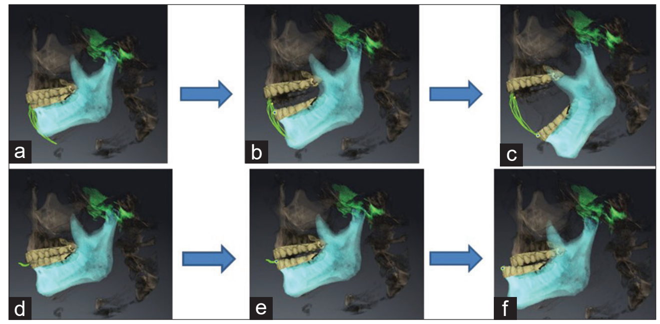

Figure 5: Patient-specific visualization of mandibular lateral movement. (a) maximal intercuspation, (b) lateral left, (c) lateral right, (d) left working, (e) right working and (f) protrusion

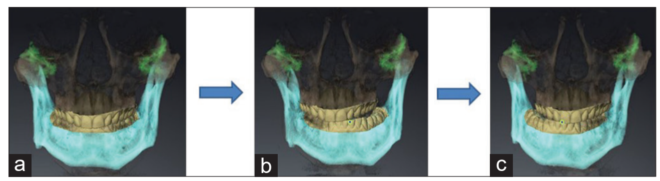

Figure 6: (a and d) Patient-specific visualization of maximal intercuspation, (b and c) mandibular working side to side movements,

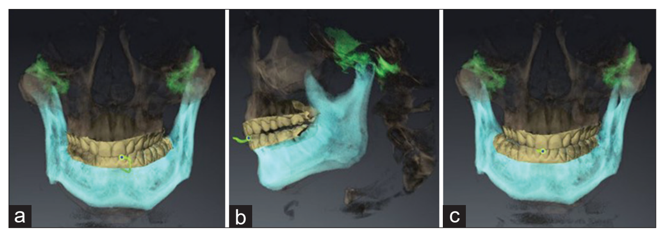

Figure 7: (a) Left lateral movement to ensure anterior guidance, (b) disengagement of the posterior teeth, (c) right lateral movement to ensure anterior guidance

SICAT Function software enables the visualization of patient-specific jaw movement relative to the patient-specific anatomy of the jaw. It is also capable of visualizing the joint space during different movements, thus providing an anatomical condylar position evaluation of jaw positions and in dynamic occlusion. Consequently, the software provides the ultimate opportunity for oral diagnostics and treatment. It can also be used in other fields of dentistry for creating mouth guards, dentures, esthetically functional reconstructions with or without tooth implants and even for simultaneous prosthetic and surgical planning.

Conclusion

The SICAT Function software can combine cone bean CT, electronic JMT data, and digital impressions; thus, it is capable of presenting a real, 3D simulation of mandibular movements relative to the patient-specific anatomy of the jaw. In addition, changes in the joint space during resting or other positions can be recorded. Thus, the system can be used as a useful supporting tool in the diagnosis, treatment, and management of TMDs.

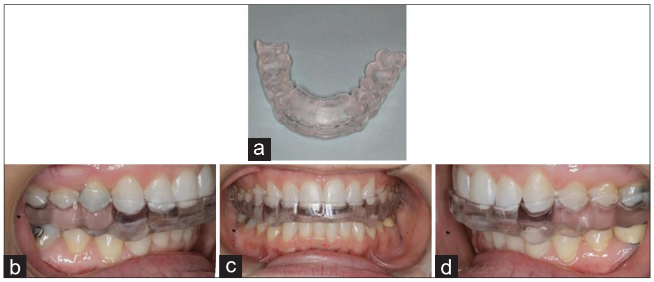

Figure 8: (a) Fabricated splint extraorally, (b) intraoral right lateral view, (c) intraoral frontal view, (d) intraoral left view

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent forms. In the form the patient(s) has/have given his/her/their consent for his/her/their images and other clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

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Nil.

Conflicts of Interest

There are no conflicts of interest.

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